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WANL - TME NO. 403

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PRELIMINARY REPORT ON AIR FLOW TESTS

FOR

CONTROL DRUM DRIVE SHAFT LOSS COEFFICIENTS

by

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DISCLAIMER

INTRODUCTION

Pressure loss coefficients are required for the coolant flow paths along the control drum-drive shaft for design and off-design conditions. The flow rate must be determined through the drive shaft flexible couplings and exhaust holes; nozzle end bearing shaft holes and plenum; inner two rings of control drum coolant holes; and the dome end bearing shaft. The effects of drive shaft exhaust hole size, nozzle end plenum depth, and nozzle end ring clearance, on flow must be determined. Measurements of the loss coefficients and determination of the flow distribution are necessary for correct sizing of (a) the drive shaft and nozzle end plenum holes, (b) nozzle end control drum plenum, and (c) the other coolant passages. This knowledge is necessary to insure a safe thermal environment for the control drum during maximum power output of the NRX-A hot tests.

The purpose of this memo is to summarize the results of preliminary air flow tests on the first control drum-drive shaft model, illustrated in Figure 1; to describe the new version of the test model shown in Figure 2; and to describe the new instrumentation and run program. The new version (J-66) was necessitated by the recent design changes of the control drum and drive shaft, thereby making the first model (J-33) obsolete before testing. It was decided, however, to flow test the obsoleted model since it was in its final stage of completion, thereby providing experience in test method and system operation. This decision proved valuable since the test data revealed that there was internal leakage within the pressure measurement system resulting from three-way and two-way plug-type flow control valves. Data for the new model can now be obtained from a modified pressure measurement network which utilizes seat-type valving.

The experiments with the J-33 configuration were made using compressed air at ambient temperature and the results are presented in the discussion that follows.

TEST PLAN

Description of the Model J-33

The test model (Figures 1 & 3) consists of a mock-up of the center two rings of control drum cooling holes in series with the control drum drive shaft. The flow passages are accurately machined so that the cross sectional geometry will duplicate the actual flow path (plenums and coolant holes) from the nozzle end of the control drum to the actuator end of the drive shaft. All coolant holes utilize tubing to simulate flow channels wherever possible, (tubing inner diameter is 0.180-inch). The mock-up utilizes a cut down commercially available coil spring instead of the actual spring.

Spring Data

	Specified	Commercial
Mean Diameter	1.000	1.000
Wire Diameter	0.280	0.250
Free Length	2.342	1.875
Number of coils	5 active	5 active
Assembly length	2.146	1.690

The drive shaft couplings are straight splined instead of crowned. The model is complete with the dome end bearing shaft, the nozzle end bearing shaft, and all of their corresponding spacers, nuts and rings.

The flow enters the model (Figures 1, 4 & 7) at the nozzle end bearing shaft where a portion of the flow passes through a ring of eight 0.250 diameter holes into a small variable plenum (spacers change plenum height), then into an outer ring of eight 0.180 diameter control drum coolant holes. The other portion of flow passes through the center hole (17/32-inch diameter) of the bearing shaft and into a large plenum containing a coil spring. Here it separates, a large portion going to the inner ring of four 0.180 diameter control drum coolant holes and the remainder going to the outer ring of eight coolant holes. The outer and inner ring of coolant flow converges at the dome end of the control drum (refer Figure 3) and passes through the hollow dome end bearing shaft. Upon discharge from the dome end bearing shaft, some of the flow may leak out through the straight shaft coupling and into a large plenum. The remainder of the flow will exit through the drive shaft discharge holes and leak through the straight coupling at the actuator end of the drive shaft. All of the flow then passes through a common plenum leading to the flow measuring nozzle and then it is exhausted to the atmosphere.

Experimental Set-up

The preliminary air tests were conducted in the Fluid Flow Laboratory. The flow loop and instrumentation are as shown in Figure 5 and Figure 6, respectively. The gas passes through a pressure reducing valve, through metering valves, into the test section and out through a measuring nozzle. The apparatus was designed so that any pressure drop along the flow path, within the limits of 50 inches of mercury, could be measured. The test model drive shaft length is one-half the actual length and the control drum length is 0.545 times the actual length.

All pressure measurement stations have two static pressure taps. There are 16 pressure stations (Figures 1 and 1 A) and two temperature stations. The pressure drops at all stations are measured with U-tube manometers, while the upstream pressure of each station is obtained with 0 to 160 psig range Ashcroft pressure gauge.

The air temperature is measured at the inlet (T1) to the apparatus and at the discharge (T2) with chromel-alumel thermocouples. Flow rates at the discharge nozzle were determined with the use of a manometer.

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CALCULATIONS

Calculations of pressure loss coefficients and Reynolds number are based on station inlet conditions.

Loss Coefficients

$$C = 2 \rho g_c \Delta P A^2 / (144 W^2)$$

where

C = pressure loss coefficient (dimensionless)

ρ = density evaluated at upstream station pressure and temperature $\frac{(lb_m)}{(ft^3)}$

g_c = gravitational constant ($32.2 \; lb_m \; ft/lb_f \; sec^2$)

ΔP = pressure drop across stations being evaluated (lb_f/in^2)

A = area (in^2)

W = mass flow (lb_m/sec)

Reynolds Numbers

$$N_{Re} = \frac{4 W}{\pi d \mu}$$

N_{Re} = Reynolds number (dimensionless)

W = Mass flow (lb_m/sec)

μ = viscosity evaluated at station temperature ($lb_m/sec \; ft$)

d = length (ft)

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RESULTS

The results of the preliminary experiments on the test model are presented in the form of total loss coefficients. They are determined for three sections: (a) the nozzle end bearing shaft, (b) the control drum, and (c) the drive shaft discharge holes.

(a) The nozzle end bearing shaft flow hole geometry consists of a ring of eight 0.250" diameter holes and an 0.531" diameter hole. It is assumed that there is no maldistribution in the flow across the hub between Stations 1 and 2, and that the pressure at Station 2 is representative of the pressure throughout the cross sectional plane perpendicular to the flow at that point. The average total loss coefficient for the nozzle end bearing shaft for Reynolds numbers between 313,000 and 320,000 is 0.8713, while the average total loss coefficient for a Reynolds number of 630,000 is 0.6515. The Reynolds number is based on the flow through the total area and its equivalent diameter.

(b) The control drum flow geometry consists of an outer ring of eight 0.180" diameter holes and an inner ring of four 0.180" diameter holes. There is a plenum which retains a coil spring located forward of the inner four cooling holes. The flow unites into a single stream at Station 7. Figure 3 shows the flow path of the fluid discharging from the control drum and uniting in the center area of the dome end bearing shaft. The two small holes in the center of the photograph are the pressure taps for Station 7. A total loss coefficient for the control drum has been determined between Stations 2 and 7. It is assumed that there is no maldistribution in flow between these two stations. The Reynolds number is based on the flow through the 0.180" diameter holes. The average total loss coefficient for the control drum for Reynolds numbers between 126,500 and 131,500 is 3.533, while for a Reynolds number equal to 259,000, the coefficient is 2.25.

(c) A total loss coefficient for the drive shaft was determined which includes the spline leakage area, the shaft discharge hole area, and the total mass flow. The total loss coefficient for Reynolds numbers of about 250,000 had a nominal value of 0.30. The Reynolds number was based on the shaft discharge holes (six 0.200" dia holes). The total spline leakage area was estimated to be 0.02658 square inches and is based on the half ring clearance at the coupling ends. The shaft splines are securely butted up against the half ring retainers.

DISCUSSION

A new test rig has been designed with the latest design changes incorporated. These changes affected the drive shaft and nozzle end bearing shaft. The pressure tap instrumentation has been increased substantially. In Model J-33, there were 32 static pressure taps; in the new model (J-66), there are 42 static pressure taps and 20 total pressure probes (Figures 2 and 2 A). It is expected that the velocity profiles for various cross sections can be obtained using the total pressure probes. Knowing the area, velocity and density at a station, we can compute the mass flow by the station. Using the total pressure probes, the mass distribution throughout the model can be determined. Knowing the mass distribution, the loss coefficients throughout the model can be obtained.

Five nozzle end bearing shafts will be tested in the new model (J-66), each shaft will provide a different ring clearance and plenum depth. Four drive shafts will be tested, each drive shaft has a different exhaust hole size.

Nozzle end bearing shaft

Ring Clearance (inch)	0.0	0.040	0.120	0.200	0.280
Plenum Depth (inch)	0.125	0.165	0.245	0.325	0.405

Drive Shaft

Discharge Hole Dia (inch)	0.200	0.250	0.300	0.350

The air and hydrogen tests of the J-66 Model consist of eight separate configurations. A drive shaft will remain in place while the nozzle end bearing shafts are changed for five tests, then a nozzle end bearing shaft will remain in place while the remaining three drive shafts are tested. Data will be used for calculation of loss coefficient versus Reynolds number for the various configurations.

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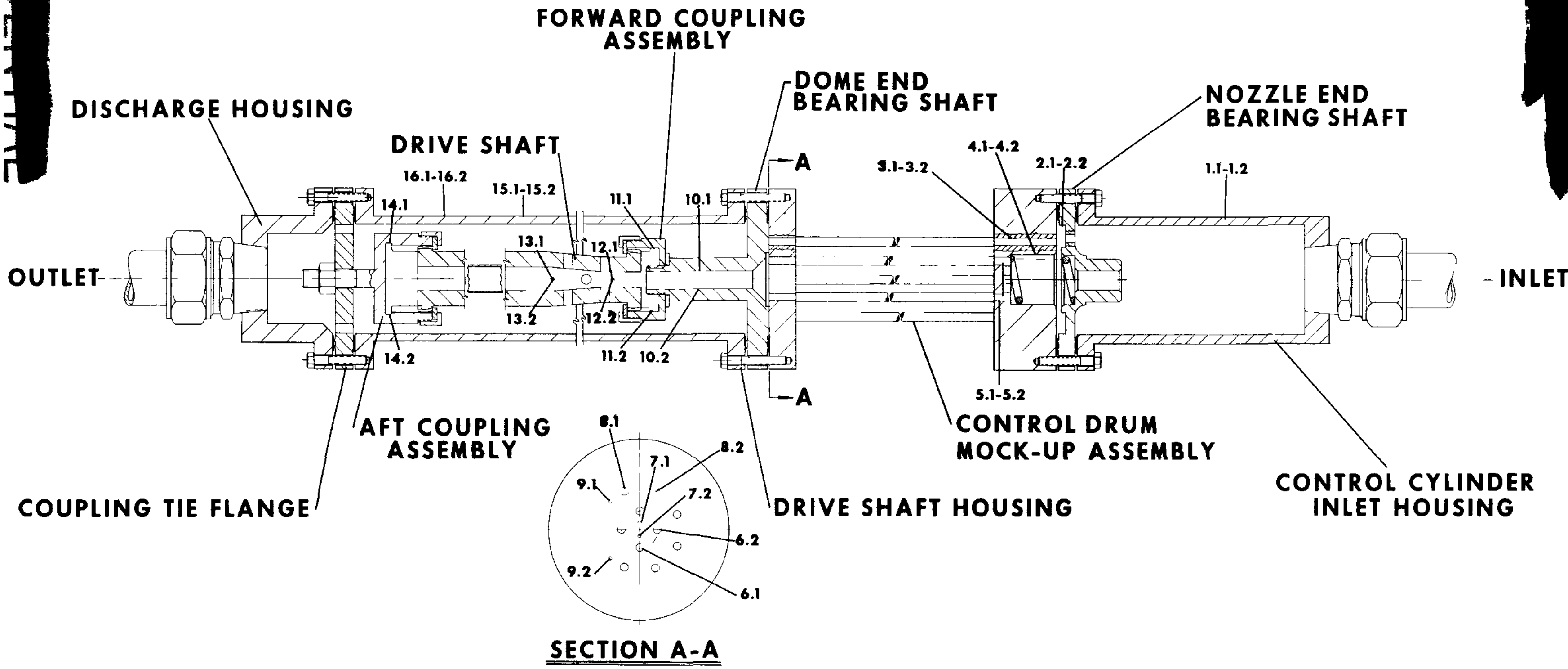

FIGURE 1 CONTROL DRUM-DRIVE SHAFT LOSS COEFFICIENT RIG J33

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STATIC PRESSURE PROBES	STATION LOCATION	
1. Bearing shaft inlet - nozzle end	1.1	1.2
2. Small variable plenum - nozzle end	2.1	2.2
3. Control drum outer ring - nozzle end	3.1	3.2
4. Large plenum at control drum inner ring inlet	4.1	4.2
5. Control drum inner ring - nozzle end	5.1	5.2
6. Control drum inner ring - dome end	6.1	6.2
7. Outer ring & inner ring converging passage - dome end	7.1	7.2
8. Control drum outer ring - dome end	8.1	8.2
9. Control drum outer ring discharge - dome end	9.1	9.2
10. Dome end bearing shaft discharge	10.1	10.2
11. Dome end bearing shaft coupling plenum	11.1	11.2
12. Drive shaft discharge holes - upstream	12.1	12.2
13. Drive shaft discharge - downstream	13.1	13.2
14. Actuator end shaft coupling plenum	14.1	14.2
15. Drive shaft discharge plenum	15.1	15.2
16. Drive shaft discharge plenum	16.1	16.2

Figure 1A - Pressure Probe Identification for Control Drum-Drive Shaft Model

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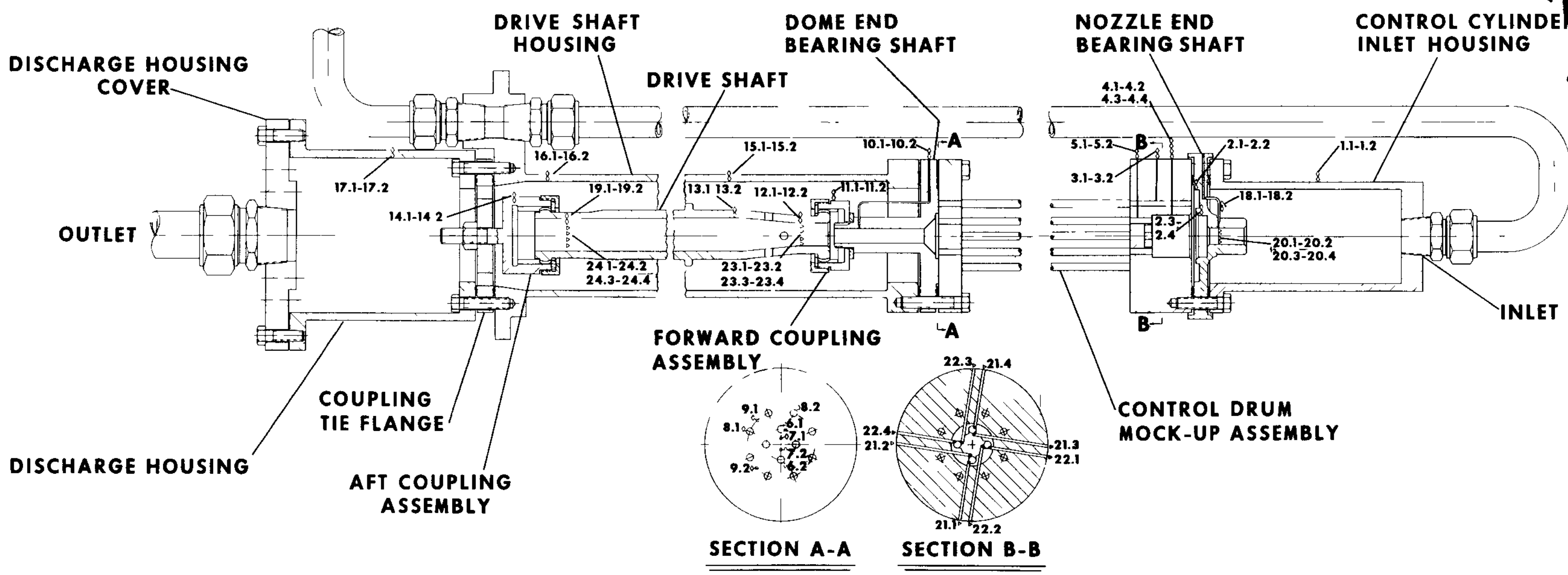

FIGURE 2 CONTROL DRUM-DRIVE SHAFT LOSS COEFFICIENT RIG J66

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STATIC PRESSURE PROBES	STATION LOCATION			
1. Nozzle end bearing shaft inlet	1.1	1.2		
2. Nozzle end				
a) Small variable plenum	2.1	2.2		
b) Bearing shaft discharge	2.3	2.4		
3. Control drum outer ring - nozzle end	3.1	3.2		
4. Large plenum at control drum inner ring inlet	4.1	4.2	4.3	4.4
5. Control drum inner ring - nozzle end	5.1	5.2		
6. Control drum inner ring - dome end	6.1	6.2		
7. Outer ring & inner ring converging passage - dome end	7.1	7.2		
8. Control drum outer ring - dome end	8.1	8.2		
9. Control drum outer ring discharge - dome end	9.1	9.2		
10. Dome end bearing shaft discharge	10.1	10.2		
11. Dome end bearing shaft coupling plenum	11.1	11.2		
12. Drive shaft discharge holes - upstream	12.1	12.2		
13. Drive shaft discharge - downstream	13.1	13.2		
14. Actuator end shaft coupling plenum	14.1	14.2		
15. Drive shaft discharge plenum	15.1	15.2		
16. Drive shaft discharge plenum	16.1	16.2		
17. Rig discharge plenum	17.1	17.2		
18. Nozzle end bearing shaft wall	18.1	18.2		
19. Drive shaft wall-actuator end	19.1	19.2		

TOTAL PRESSURE PROBES				
20. Nozzle end bearing shaft	20.1	20.2	20.3	20.4
21. Control drum cylinder plenum	21.1	21.2	21.3	21.4
22. Control drum cylinder plenum	22.1	22.2	22.3	22.4
23. Drive shaft inlet	23.1	23.2	23.3	23.4
24. Drive shaft discharge	24.1	24.2	24.3	24.4

Figure 2A - Pressure Probe Identification for Control Drum-Drive Shaft Model

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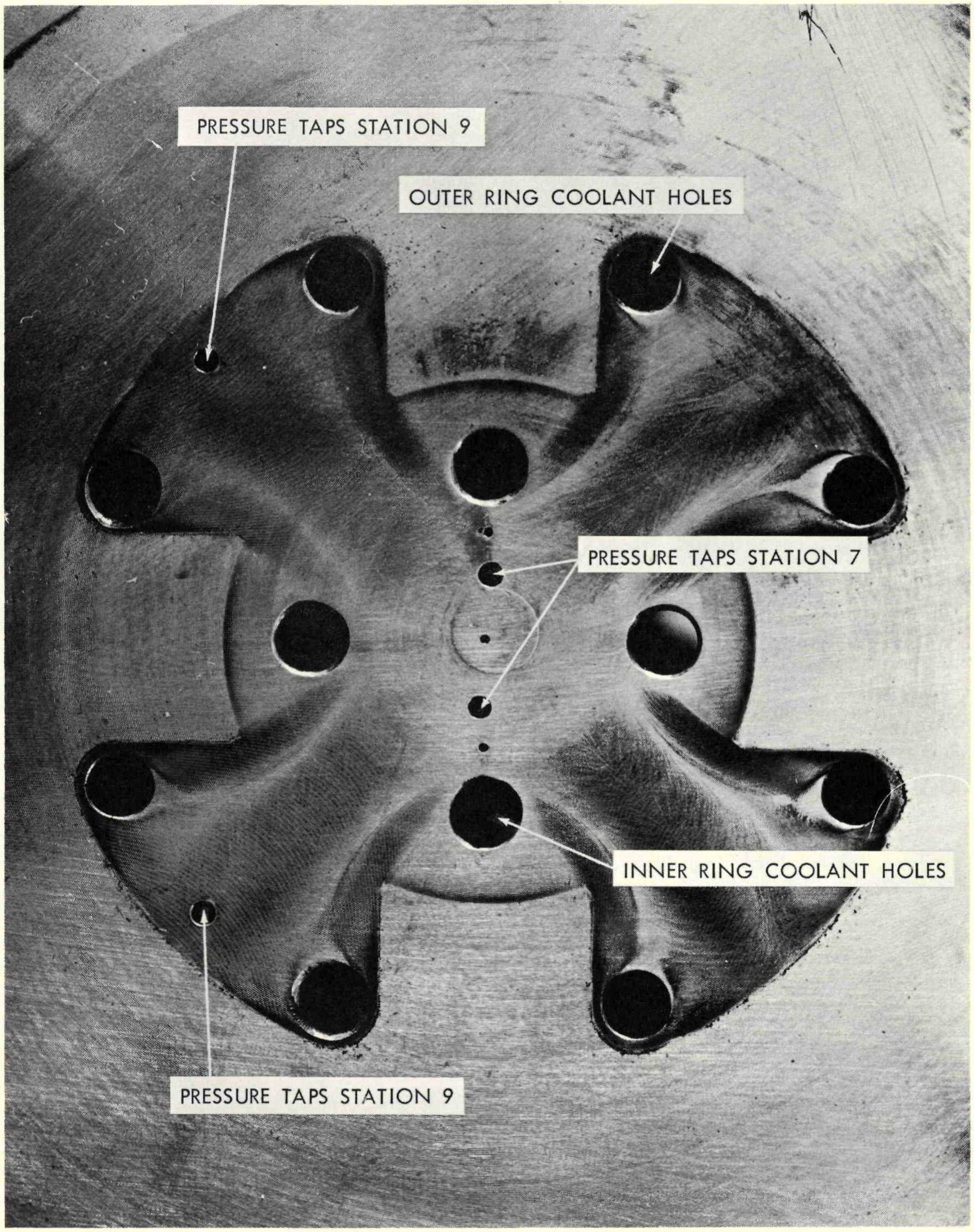

FIGURE 3

CONTROL DRUM DOME END DISCHARGE

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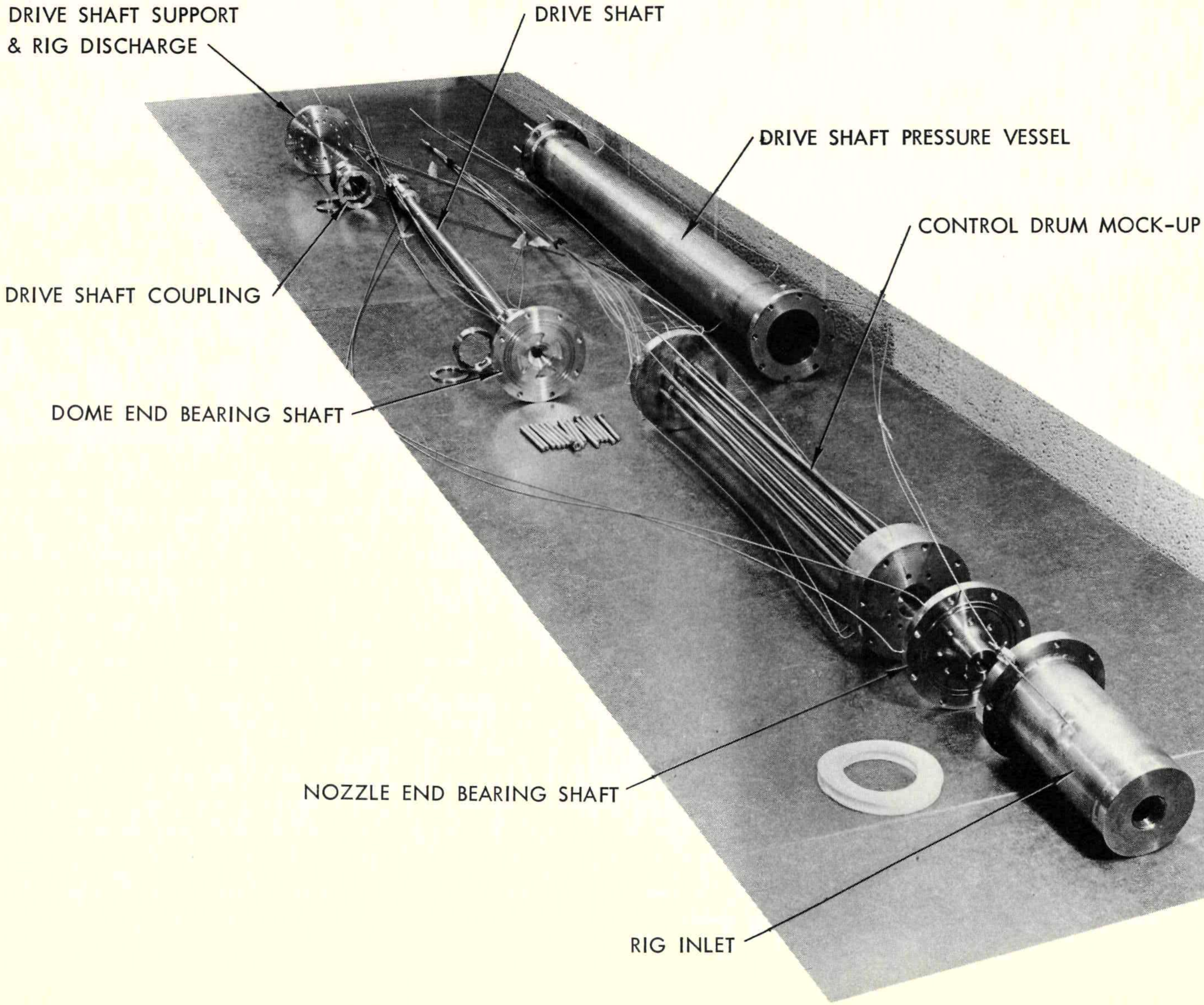

FIGURE 4
CONTROL DRUM - DRIVE SHAFT RIG

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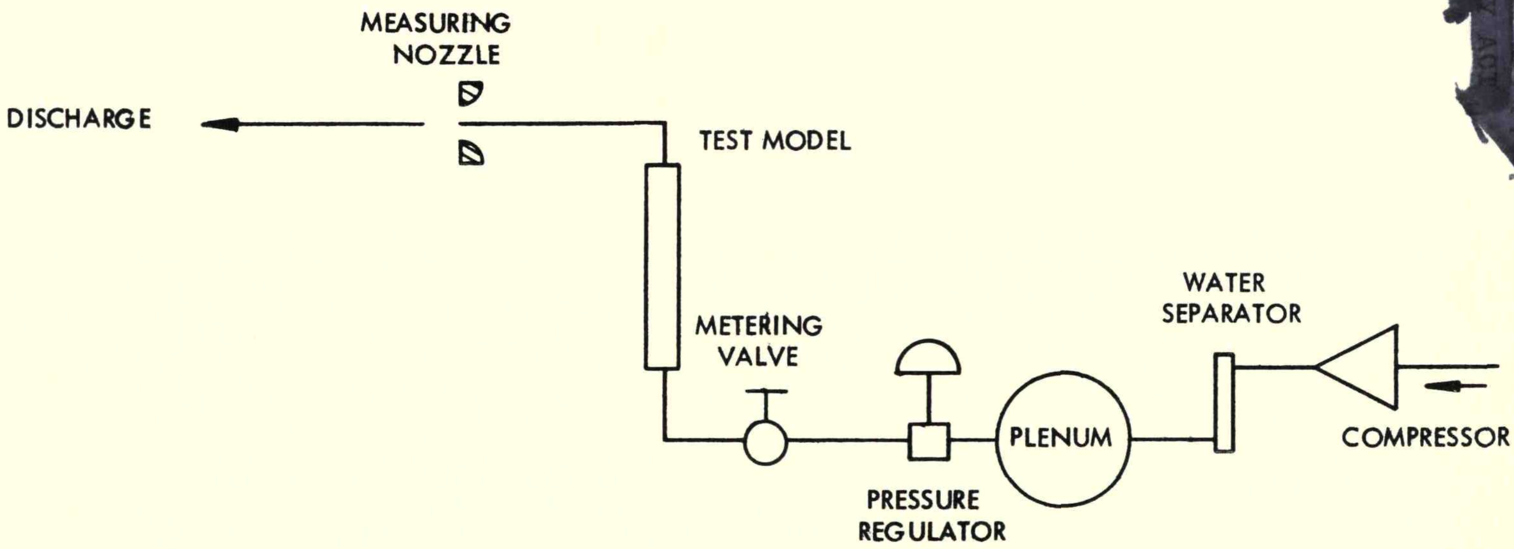

FIGURE 5
AIR FLOW LOOP FOR CONTROL DRUM-DRIVE SHAFT LOSS COEFFICIENTS

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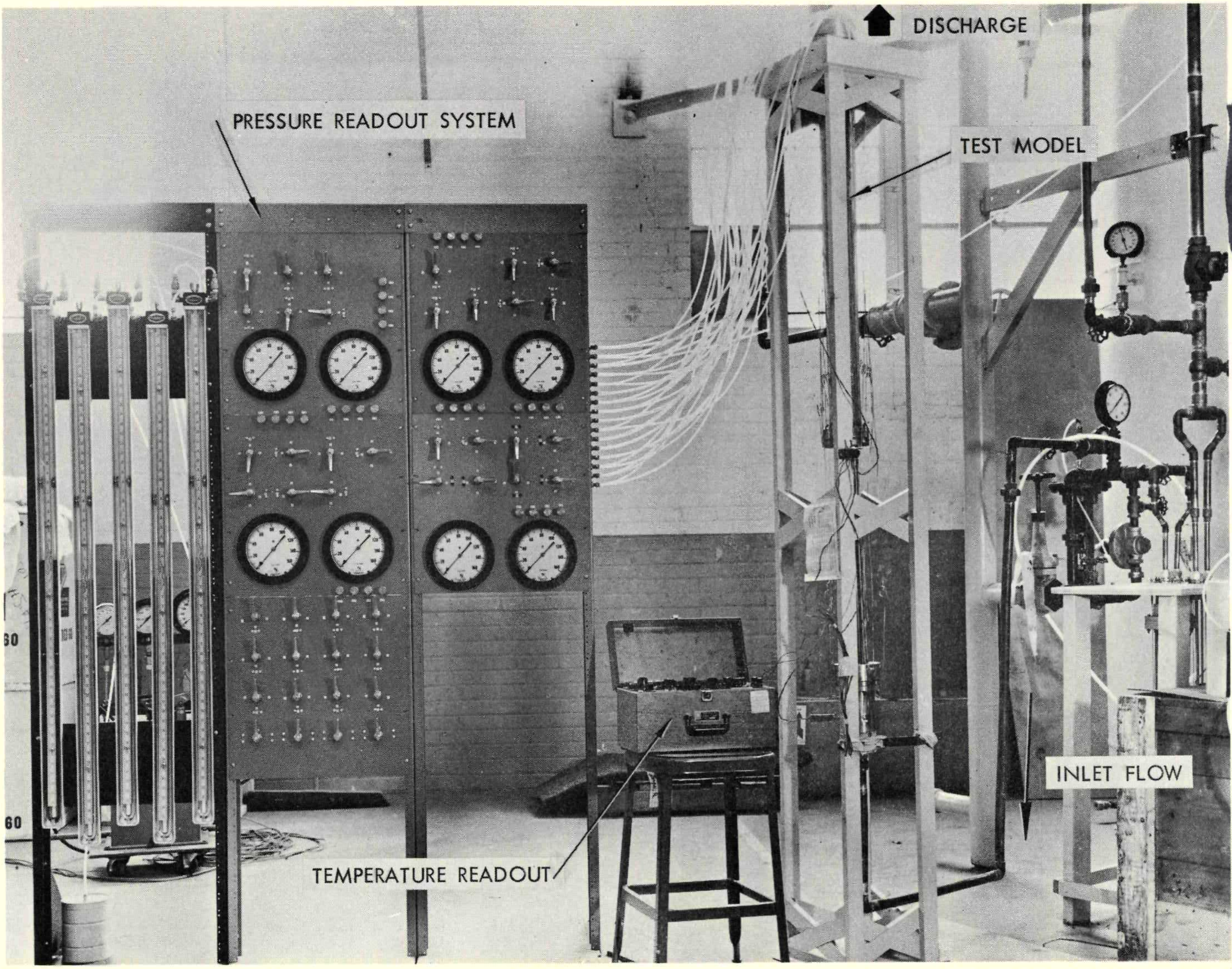

FIGURE 6
CONTROL DRUM - DRIVE SHAFT
TEST SET - UP

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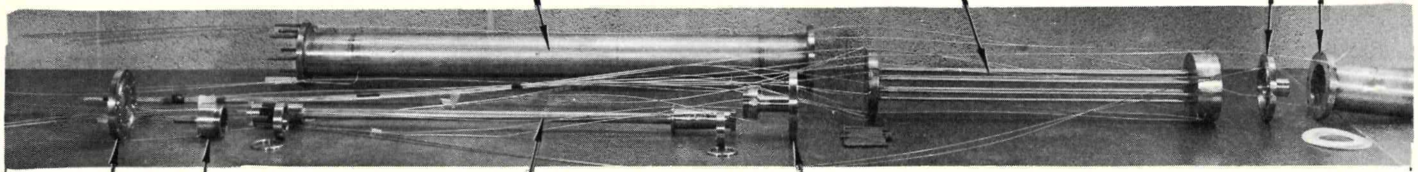

FIGURE 7

CONTROL DRUM - DRIVE SHAFT RIG

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